Method for Predicting Seasonal Outdoor Thermal Environment and Building Cooling Load

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論　文　内　容　要　約

1. Introduction

The global warming has been recognized for many years, and in the urban area, the air temperature increases due to urban heat island effect. These two phenomena cause the health hazards in urban area and increase the building's cooling load. Under such circumstances, previous researches have investigated the influences from the building shadows and urban ventilation caused by different building arrangement, and also the influences from the different urban surface materials. Evaluations on the outdoor thermal environment were made based on the numerical simulations under these different conditions.

In simulating the outdoor thermal environment for an urban area, it is necessary to reproduce very complicated 3-dimensional radiant heat transport and turbulent flow field around buildings within the simulation area with high accuracy, thus huge amounts of computations are needed to simulate the complex environment. According to this limitation, the numerical simulations of the outdoor thermal environments were carried out only for short periods, usually for the worst condition or the typical condition of the sunny day in summer. On the other hand, for predicting the building cooling load in the summer season, the long period analysis for a single building has been widely used. The weather data collected from the weather stations were commonly used in predicting the cooling load in the summer season, which was the common type of the weather conditions in the city, but the influences of surrounding buildings were not considered.

In this study, a new method was proposed to predict the outdoor thermal environment and the building cooling load influenced by the outdoor thermal environment in the summer season for a long time with introducing the artificial neural network into the prediction process.

2. Thesis structure

The thesis was composed of total 7 chapters.

Chapter 1 reviewed the previous researches, found the problems existing in the previous researches and gave the structure of this thesis.

Chapter 2 firstly outlined the methods of predicting the outdoor thermal environment and building cooling load.

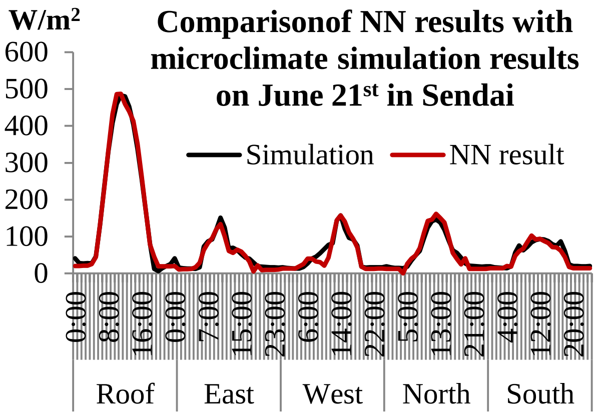
Then the basic equations which were involved in the numerical simulation were introduced, and analysis methods of predicting the outdoor thermal environment and building cooling load were described.

Chapter 3 discussed the factors that influence the heat balance analysis results. Cities with different latitude were concentrated on. Guangzhou, China, and Sendai, Japan were selected as the example cities to carry out the comparison of the building surface heat gain between the two cities. To clarify the influence of solar radiation when it shows its maximum value, June 21st was selected as the simulation date for the sun reaches its highest altitude at the summer solstice in June 21st. Results showed that the surfaces with direct sunshine had more radiation heat gain, especially on vertical surfaces, and the higher air temperatures resulted in more heat gain on the surfaces.

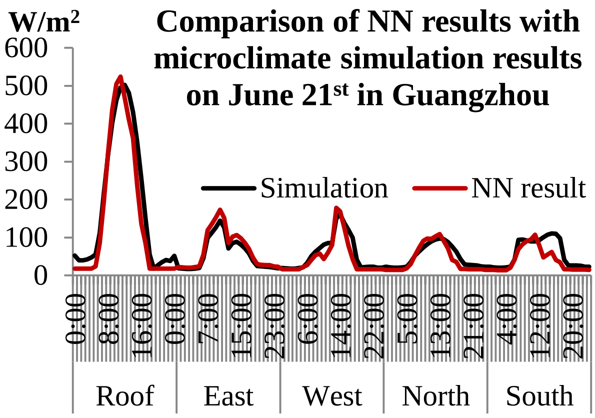
Chapter 4 discussed the factors that influence the SET* values. The outdoor thermal environments were analyzed for 2 groups of cities, the analysis times were all at 12:00 local solar time on June 21st when the sun reaches its highest altitude during the whole year. The first group kept focusing on change in the latitude, where the radiation environments were different and the wind velocity and humidity were set to the constant value. Guangzhou, Wuhan, Beijing and Harbin were selected in this group, the MRT (Mean Radiant Temperature) and SET* were compared in this group in order to evaluate the influence of the outdoor radiation environment on the SET* distribution. Group 2 focused on the influence of the change in wind velocity on the change in SET* distribution. In this group, coastal city Shanghai and inland city Wuhan were selected. The changes in the outdoor thermal environment with the weather conditions were analyzed. It was found out that building shadows and vertical surfaces temperatures influenced the MRT value and thus influenced the SET* value, higher air temperature also resulted in higher SET* value, and higher wind velocity decreased the SET* value.

Chapter 5 demonstrated the methodologies involved in the long period analysis with the introduction of artificial neural networks. The methods for determining the typical days and the architecture method of artificial neural networks were also mentioned in this chapter.

Chapter 6 built the neural networks with the factors that were determined in chapters 3 and 4. Sendai was selected as the city to carry out the case study. According to the standards from JMA, the summer season of Sendai was determined from July 1st to September 13th, and 5 types were clustered for the 75 days. The typical days of the 5 types were August 2nd (cool, sunny), August 7th (hot, sunny), August 10th (windy), August 26th (rainy), September 9th (cloudy). Building cooling load and SET* around the building were calculated on typical days. The weather data and the simulation results on the typical days were used as the training data for building the artificial neural networks for the surface heat gain value and acceptable SET* area ratio in the whole summer season separately. The optimal numbers of hidden neurons were discussed, and the neural networks were trained repeatedly in order to get the one with the best predicting performance. The optimal neural networks were validated using the simulation results on June 21st in the analyzed cities, which were obtained in Chapters 3 and 4, and it was found that the trained neural networks were able to predict the building surface heat gain and the ratio of acceptable area where SET* value is lower than 35°C in Sendai as shown in Figure 1 (1) but were not so effective when applying them to the other cities as shown in Figure 1 (2). This indicated that the neural network prediction was not effective when predicting the weather condition far beyond the training data, and implied that both of the best and worst conditions should be considered in the training process. The newly proposed prediction



(1) Sendai



(2) Guangzhou

Figure 1 Comparison of NN results with microclimate simulation results in Sendai and Guangzhou

(Training the neural network with weather data and simulation results on 5 typical days in Sendai)

method used the evaluation indices of 1) cooling load of the target building (Figure 2), 2) net effluence heat from the building surface to the urban atmosphere based on the heat balance analysis (Figure 3) and 3) acceptable SET* ratio based on the SET* calculation (Figure 4). With the optimal neural networks trained in this chapter using the simulation result in Sendai, evaluations of these three indices were made to an ideal building located in Sendai.

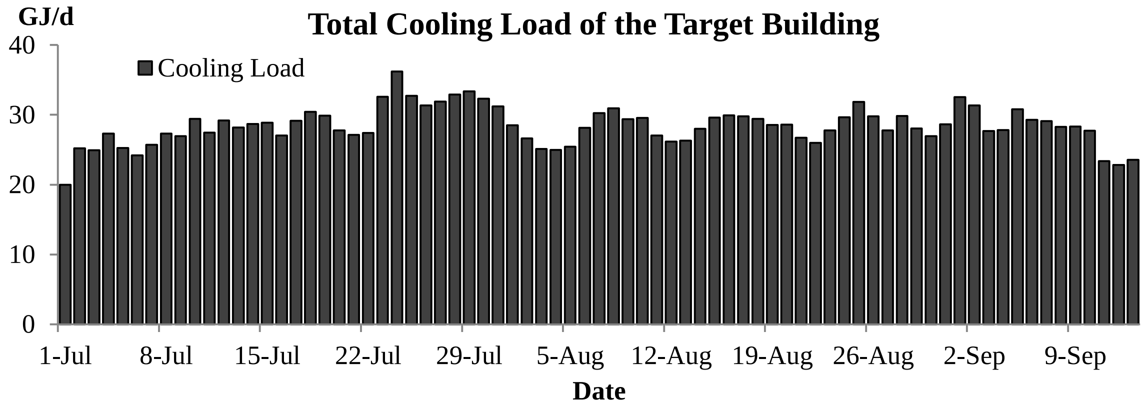


Figure 2 Total cooling load of the target building in Sendai during summer season

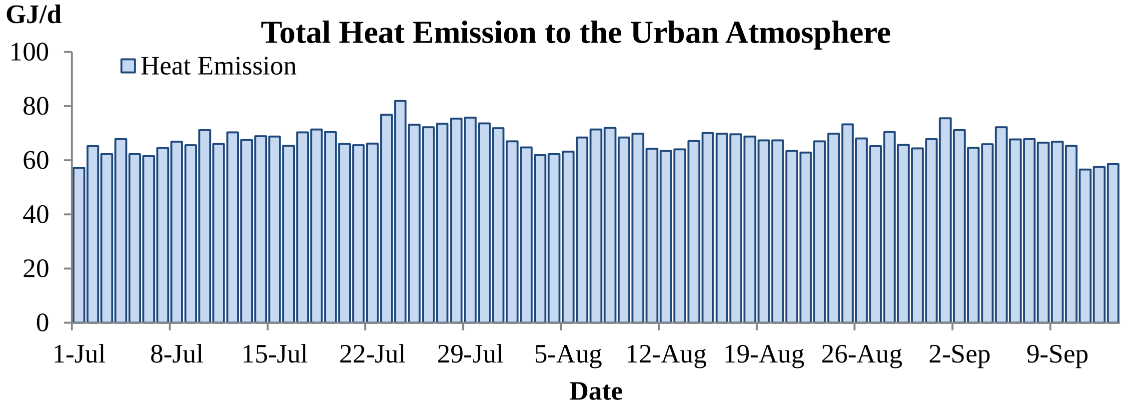


Figure 3 Total heat emission to the urban area from the target building in Sendai during summer season

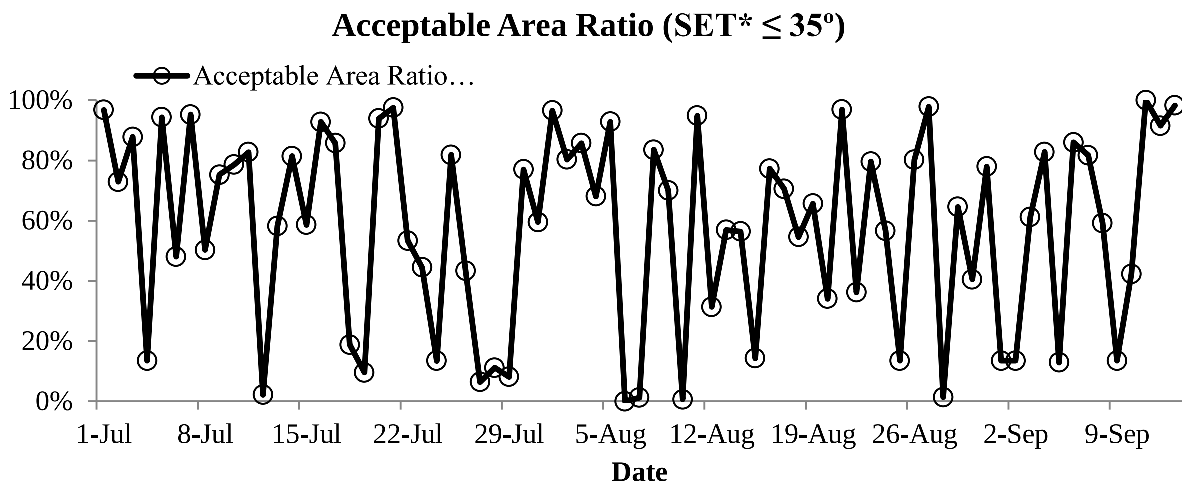


Figure 4 The ratio of acceptable area where SET* ≤ 35°C
around the target building in Sendai during summer season

Chapter 7 concluded the whole study, demonstrated the highlights and what we needed to do in the next step.

3. Concluding remarks

1) The factors that influence the outdoor thermal environment and building cooling load were determined (Chapters 3 and 4).
   With the numerical simulation on June 21st in 6 cities in China and Japan (Sendai, Harbin, Beijing, Shanghai, Wuhan and Guangzhou), the factors that influence the radiation environment and SET* value at pedestrian level were determined.
2) Based on the determined factors, a long period analysis method for predicting the outdoor thermal environment and building cooling load with the concern of surrounding buildings was proposed (Chapters 5, 6).
   The inputs for predicting the surface heat gain were 1) solar altitude, 2) solar azimuth, 3) solar radiation intensity, 4) outdoor air temperature at each time, and 5) surface directions, 6) locations of the cells (located at the boundary of the surface or not).
   The output was the surface heat gain of each cell at the simulation model of the building.
   Because of the difficulty to predict the SET* distribution with the neural network, the ratio index rather than the SET* value was used in building the neural network.
   The inputs for predicting the SET* ratio were 1) inlet wind velocity, 2) absolute humidity, 3) air temperature, 4) radiation intensity at the same time the outdoor thermal environments were carried out and 5) region indicator which is related to the building shadow, 6) region indicator which is related to the wind velocity distribution.
   The outputs were the 1) average SET* value in each region, 2) the ratio of the area where SET* ≤ 35°C in each region, and 3) the ratio of the area where SET* ≤ 40°C in each region
3) The accuracy of the newly proposed analysis method was validated (Chapter 6).
   The neural networks were built and trained with the simulation result on 5 typical summer days in Sendai. With the neural networks built for building surface heat gain and acceptable SET* area ratio, the accuracy of the

neural networks were examined by comparing its results with the simulation data on June 21st obtained in Chapters 3 and 4.

The high accuracy of the proposed method was confirmed for Sendai, but the accuracy was not sufficient for other cities. This indicated that the extreme conditions (the best and worst conditions) should be considered when training the neural networks.

4) Based the newly proposed analysis method, evaluations on 1) mitigation of global warming, 2) mitigation of urban warming and 3) adaptation of urban warming in an ideal urban area model in Sendai were made (Chapter 6).

This simulation method is capable for predicting the urban outdoor thermal environment, and the building cooling load influenced by its surrounding area for a long period. Compare to the traditional short period methods, evaluations based on this method can provide an overview of the outdoor thermal environment change and its influence on the building cooling load for a long period. The prediction method can be a powerful tool for understanding the characteristics of a long time variation of outdoor thermal environment and its influence on building cooling load.